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An integrated ecosystem incorporating renewable energy leading to pollution reduction for sustainable development of craft villages in rural area: a case study at sedge mats village in Mekong Delta, Vietnam

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Abstract

Background: The sedge mats (dyeing, weaving processes, and small-scale livestock farm at the same place) craft villages in the Mekong Delta (Vietnam) are the most popular craft villages in Vietnam, especially in the Mekong Delta area. These craft villages generate typical emissions such as exhaust gas from burning fuel, wastewater from the sedge mats dyeing and weaving process, wastewater from livestock farm, and solid waste.

Methods: In this study, an ecological system, so-called VICRAIZES (Vietnam Craft villages Agro-based Industrial Zero Emission System), has been developed with the purpose to decrease pollution and enhance resource efficiency at those craft villages. The proposed ecosystem focused on measures such as (1) biogas tank (using residue pieces of solid sedge mats from weaving processing) supplied gas for burning the dyeing tank, (2) wastewater treatment system combining three components: innovative septic tank having upward flow thin baffles, anaerobic filter compartment, and bio-pond, and (3) composting area. The system was applied for a number of household craft villages in Dong Thap Province, Vietnam.

Results: The results of system demonstration show significant emission decreases: 93 % greenhouse gas (CO_2 and CH_4), 97 % BOD_5 in wastewater, around 30 kg/day biodegradable garbage are composted and used as organic fertilizers at the household needs (which increase family income of around 115 million VND/year), low initial investment and operating cost, simple operating procedure, etc., which are favorable and applicable at the low income sedge mats dyeing and weaving craft villages in the Mekong Delta area, Vietnam, and probably at other developing countries.

Conclusions: The VICRAIZES system implementation shows remarkable benefits/advantages on environmental, economic, and technical aspects giving real chances for more comprehensive application at similar craft villages in Vietnam and possibly in other developing countries.

Keywords: Renewable energy, Biomass, Ecosystem, Sedge mats, Craft villages, Mekong Delta, VICRAIZES

Abbreviations: AIZES, Agro-based Industrial Zero Emission Systems; BOD, Biochemical Oxygen Demand;
(Continued on next page)

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BSSF-CW, Buried Subsurface Flow Constructed Wetland; COD, Chemical Oxygen Demand; CWs, Constructed Wetlands; DOC, Dissolved Organic Carbon; IPCC, Integrated Pollution Prevention and Control; GHG, Greenhouse Gas; HFCWs, Horizontal Sub-surface Flow; QCVN, Vietnam National Technical Regulation; SBR, Sequencing Batch Reactor Technology; TN, Total Nitrogen; TP, Total Phosphorus; TSS, Total Suspended Solid; VICRAIZES, Vietnam Craft Villages Agro-based Industrial Zero Emission Systems; VNU-HCM, Viet Nam National University – Ho Chi Minh City; WWTP, Waste Water Treatment Plant; VND, Vietnam Dong

Background

Case study description and problems involved

Together with high social and economic efficiency, *craft village activities* in the Mekong Delta area have negative *impact on the environmen*t and public health. The typical craft village is a group of households having craft production and living activities at the same place. It contains many point source pollutions (from small-scale manufacturing households), which could directly affect negatively on the whole residential living area. The survey results of Chi (as well as other studies) indicated that 100 % wastewater samples taken from surveyed craft villages have exceeded permissible discharge standards, surface and groundwater at the village area are polluted significantly at different level, and the air pollution in the craft villages is observed at the processing area (due to dust, exhaust gas from burning coal fuel, wood. etc.) [1]. Fortunately, there is no signal on soil pollution at the survey areas. Most pollution sources in the craft villages (in Vietnam in general, and particularly in the Mekong Delta area) have no treatment prevention measures.

Due to an abundant material source, sedge mats craft profession is one of the most popular ones in Vietnam and concentrated mostly in Mekong Delta area. Sedge mats dyeing and weaving craft villages account for about 10.8 % of the total number of craft villages in Mekong Delta and are distributed in all over 13 provinces in Mekong Delta area; they contributed to solving employment for more than 180,000 employees in the area. At typical case is the Dinh Yen Commune (Lap Vo District, Dong Thap Province) where there are 4399 households; among those are 1530 households participating in the activities related to the sedge mats dyeing and weaving, with an average of five persons for each household. The technology for the dyeing and weaving of sedge mats at the craft villages comprises of major steps such as the preparation of raw material (sedge after drying) → dyeing (soaking sedge material into a pan having dyeing solution at temperature above 80 °C maintained by combustion of wood/rice straw/small pieces of sedge) → first drying (naturally by solar heat) → softening (soaking dyed sedge into water in some minutes) → weaving (by hand or using weaving machine) → second drying (again by natural solar heat) → completion (cutting of the margin/edge, surface polishing, printing, and designing pattern). The processing flow chart is presented in Fig. 1.

The main environmental issues are:

Use of inappropriate fuels causing heavy air pollution
Some of the households even use waste tire, waste rubber sandals, and other plastic wastes as fuels for burning the dyeing pan (Fig. 2).
In the sedge mats dyeing and weaving craft villages, 55 % of the households use pieces of sedge as fuels (corresponding to 180,675 tons/year), 40 % use straw (8212 tons/year), and less than 5 % use another fuels (such as in Fig. 2). Volume of emission gases from burning fuel in the sedge mats dyeing and weaving craft villages in Mekong Delta is summarized in Table 1.
Wastewater
Wastewaters from dyeing are not properly collected and treated causing heavy pollution for the receiving sources (Fig. 3).
The wastewaters generated from the sedge mats dyeing and weaving craft villages in Mekong Delta include domestic wastewater, wastewater from the sedge mats dyeing and weaving processes, and wastewater from livestock farm (if any, depending on each household), with total quantity of wastewater of less than 10 m^3/day/household. The typical concentrations of pollutants in wastewater flow are as follows: COD = 6380 mg/L, BOD_5 = 3425 mg/L, TSS = 81 mg/L, color = 15,150 Pt-Co, total N = 225 mg/L, and total P = 98.63 mg/L (average results obtained from three sampling replicates at three different households, implemented by authors during the time of site investigation).
The organic solid waste from the craft process
There is practically no solid waste collection system in the rural area in Mekong Delta, and the households find ways to treat it by themselves. Domestic solid waste is normally dumped, incinerated, or disposed indiscriminately. At the sedge mats dyeing and weaving craft villages, solid waste (pieces of sedge are described in Fig. 4) that is normally reused for cooking (heating, boiling) the dyeing pans or used for covering the plants garden in order to prevent weeds development, to keep the soil moisture, or to avoid soil erosion.
In brief, sedge mats dyeing and weaving jobs in Mekong Delta rural area in Vietnam have been causing heavy environmental problem in air, soil, and water environment. Thus, this research proposes a system

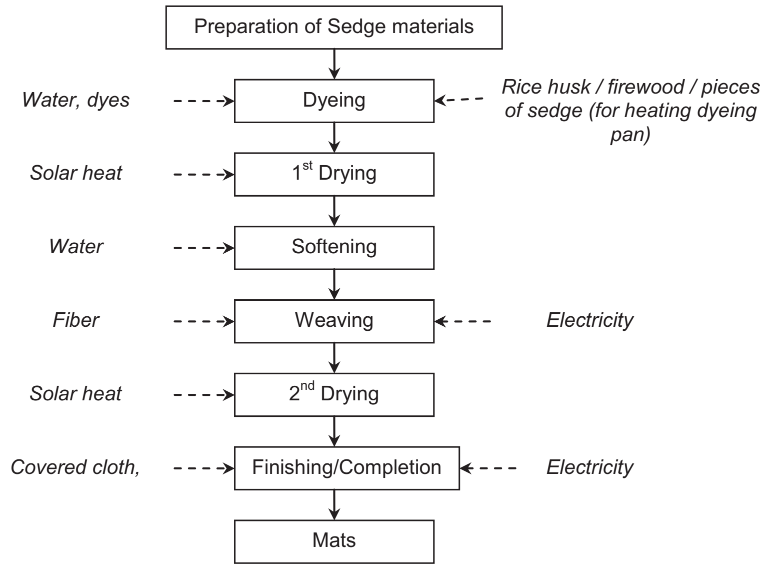

Fig. 1 Processing flow chart in the sedge mats dyeing and weaving craft production

incorporating solutions such as efficient use of renewable energy, biomass generation, and ecological techniques applying at the family scale for the purposes of pollution minimization, increase of household income, and maintaining the sustainable livelihood for the local inhabitants in the craft villages in poor rural areas.

Literature review

Application of ecosystems for decreasing pollution

The ecosystems for decreasing environmental pollution have been developed and applied worldwide, and in Vietnam as well. The "Garden – Livestock farm" is a popular system worldwide which plays an important role in rural economic development: increase the cultivation yield, soil remediation, and reduce of cost for fertilizer and livestock food [2]. This system has found an application in various developed countries such as in the USA [2–5] and in France [6, 7]. Kaufmann developed a low carbon emission system applied for livestock farm in which the livestock waste and food garbage were used for biogas digestion, the methane gas was then collected and use for cooking at the household kitchen and/or filtered and stored for supplying outside, and the residue and wastewater after biogas digester were used as fertilizer [8].

Application of eco-techniques for wastewater treatment

Many eco-techniques have also been applied for wastewater treatment taking advantages of available site natural conditions, especially the natural and constructed wetland. In the Ileydagi village, Turkey, the combined treatment system consisting of a combination of buried sand filtration (BSF) (582 m$^{2)}$ and buried subsurface flow constructed wetland systems (BSSF-CW) (1352 m$^{2)}$ is applied to treat domestic wastewater from a village having 313 inhabitants situated

Fig. 2 Waste materials are being used as burning fuels

Table 1 Volume of emission gas/greenhouse gases from burning fuel in the sedge mats dyeing and weaving craft villages in Mekong Delta area

Type of fuel	Load of emission gas (tons/year)[a]					Load of GHG (tons/year)[b]			Volume of greenhouse gases, tons CO_2eq/year
	Dust	SO_2	VOC	NO_x	CO	CO_2	CH_4	N_2O	
Firewood/Others	123.2	1.6	377.8	11.5	1149.7	9197.4	16.4	3.3	10,521.2
Rice husk	1642.5	262.8	525.6	407.3	4559.6	191,844.0	157.7	9.2	197,896.3
Pieces of straw	1499.6	32.5	1264.7	411.9	16,802.8	212,654.5	1732.7	0.0	249,040.6
Total	3265.3	297.0	2168.1	830.8	22,512.0	413,695.9	1906.8	12.5	457,458.1

[a, b]Calculated by using the formula: activity data × emission factor, in which, [a]Emission factor is taken from WHO, 1993; [b]Emission factor is taken from IPCC, 2006

near Egirdirlake [9]. Constructed wetlands with horizontal subsurface flow (HFCWs) have been used not only for common domestic wastewater but also on special wastewaters such as pharmaceutical, chemical, leather, textile, pulp paper, food, and livestock farm [10]. Constructed wetlands (CWs) have also been used as a green technology for various wastewaters from small communities in remote areas [11]. A system of constructed wetlands with horizontal subsurface flow applied at a mountain village in Czech Republic showed the wastewater treatment performance: 88–94 % for BOD_5, 67–85 % for COD, 74–96 % for TSS, 53 % for total N, and 59 % for total P [12]. In the research for domestic wastewater treatment from Büyükdöllük village in Edirne by using horizontal flow wetland system cultivated with reed on the land surface, the results showed that the treatment efficiency depends much on hydraulic loads [13]. In Thailand, the Phayao and Koh Phi Phi provinces used 140–180 m^2 and 750 m^2 as horizontal flow wetland system for treatment of different wastewaters [14]. The wetland systems for wastewater treatment normally require large land area [15]. Other authors have evaluated the feasibility of applying constructed wetland in limited land areas in Taiwan, and the results showed that using plant cultivation in wetland areas could remove nutrients much better than without using it [15]. A horizontal surface flow constructed wetland system using sand and reed has been implemented in Can Tho University, Vietnam, for the purpose of evaluating treatment capability and velocity in the tropical condition [16]. This research indicated that domestic wastewater could be treated when using that system and the effluent quality reached the country's environmental standards as required [16]. There are also many studies on wastewater treatment by using pond, lake, and plant ecosystems [17], water hyacinth and buffalo spinach [18], water hyacinth culture—algal culture—water hyacinth culture [5], *Eichhornia crassipes*—a water hyacinth species [19], cattail (Typha sp.), and reed (Phragmites sp.) [20], rice [21], water spinach [22], or emergent marsh and meadow [23].

Important pollutants in textile effluent are mainly dyes that are the most difficult constituents of the textile wastewater to be treated. Azo-dyes are the class of the most widely used dyes industrially having a world market share of 60–70 %. The residues of dye presented in the effluent may consist of 50 % of the influent flow [24], and these cause the textile wastewater high color, and high pollutants concentration. A research on using sequencing batch reactor technology (SBR) to decolorize the dyeing wastewater was done in Erode, Tamil Nadu, India, and results show that the color and COD removal efficiencies were 86.6 and 96 %, respectively [25]. The separate use of biological treatment methods as SBR and

Fig. 3 A natural pond—receiving source of wastewater—is heavy polluted by the dyeing process wastewater

Fig. 4 Solid waste from sedge mats production

oxidation method cannot help textile wastewater to meet discharge standards; however, the integration of Fenton's oxidation process with a downstream SBR provides much better removal of organic matter (88–98 % for COD, 83–95 % for BOD_5, and 91–98 % for DOC—values depending on the particular textile effluent being used) and color (>99 %) [26]. Punzi and colleagues have suggested that the use of ozonation as short post-treatment after a biological process can be beneficial for the degradation of recalcitrant compounds and removal of toxicity of the textile wastewater [27].

Physico-chemical solutions for air pollution reduction from burning process

The air pollution from burning fuels is a typical matter at small-scale craft industry in developing countries. Coal, firewood, rice husks, gasoline, sawdust, etc. are commonly used fuels in the cheap and simple burners. Absorbing method using $Ca(OH)_2$ solution, KOH solution, NaOH solution, activated carbon, silica gel, zeolite, etc. in the absorption devices (wet scrubbers in form of buffer tower, disk tower, spray tower, etc.). Particularly, dust is removed by applying devices such as deposition chamber, cyclone, fabric bag filter systems, electrostatic precipitators, and wet dust filter systems [28, 29]. In the world, in order to treat toxic organic solvents, new adsorbents having large adsorption capacity have been used [30]. Some companies in the USA, the Netherlands, the UK, the Germany) such as NORIT, CANGOL, LABCONCO, and TROX have studied and released in international market a lot of the materials and the different environment treatment equipments [30–33].

Air pollution reduction by using cleaner alternative fuels

Biomass combustion systems are non-polluting and offer significant protection of the environment. The reduction of greenhouse gases pollution is the main advantage of utilizing biomass energy [34]. Biogas, a clean and renewable form of energy, could augment conventional energy sources [35]. Biogas is one of biomass energy. Biogas is a clean fuel because it burns without leaving soot or particulate matter, and also, since it is lighter in terms of carbon chain length, less amount of carbon dioxide is released into the atmosphere during combustion. Biogas technology has helped some countries in many ways through income generation, life-style improvements, and cost saving [35]. Biogases from biogas-digester comprise of 40–75 % CH_4, 25–40 % CO_2, and other gases such as H_2S and NH_3 [36]. Many countries such as China, India, Nepal, Thailand, Germany, USA, and Denmark have long experiences in the development of biogas programs and projects [36]. One cubic meter gas mixture with 6000 cal may be equivalent to 1 L of alcohol, 0.8 L of petrol, and 0.6 L of crude oil, 1.4 kg coal or 1.2 kWh electricity, that can be used to operate 2-KVA generator in 2 h, or for lighting device in 6 h, for the refrigerator 1 m^3 biogas/1 h, or using for cooking at the household of around five people in 1 day. Biomass is becoming increasingly important globally as a clean alternative source of energy to fossil fuel as a result of rising energy demand, high cost of fossil fuels, dwindling fossil fuel reserves, and contribution of fossil fuel usage to greenhouse effect [37].

Solutions for conversion of organic solid waste

Composting is one of the best-known processes for the biological stabilization of solid organic wastes by transforming them into a safer and more stabilized material (compost) that can be used as a source of nutrients and soil conditioner in agricultural applications [38, 39]. The composting processes using municipal garbage and plants have been mentioned by many authors [35, 40–44]. Municipal sewage sludge can be a source of valuable fertilizer, due to its high content of organics, nitrogen, phosphorus, and trace elements. However, the presence of pathogenic organisms may pose health risks, limiting the direct application of sludge to soil fertilization. Therefore, sludge should be treated prior to application by methods such as composting [45]. Wang have reported that the application of well mature organics promotes the plant growth and increases soil fertility [46]. There is practically no collection and treatment system in the majority of rural areas in Vietnam, and most of households use self-treatment measures by different ways such as open dumping, incineration, or even discharging directly into the surrounding environment [47]. There are currently some garbage treatment methods in which organic solid waste is converted into organic fertilizer being in use in households in rural areas in Mekong Delta [47]. A research done at College of Agriculture and Applied Biology, Can Tho University, indicates that fertilizing 10 tons compost/ha in the first Fall-Winter rice crop could contribute to increasing yield up to 10.4 % compared with no fertilizing, and fertilizing 5 tons compost/ha in two rice crops continuously (Autumn Winter and Winter Spring) increased number of tillers and yield up to 8.08 tons/ha (Jasmine85 seedling) in the second Winter-Spring rice crop [48]. Thus, using organic waste as fertilizer has given significant effects on economics and environment.

The AIZES

The Agro-based Industrial Zero Emission Systems (AIZES) have been applied in some successful case studies. AIZES is a combination of the utilization of renewable energy with energy efficiency measures. In other countries, especially in EU (Germany, Austria, Croatia, etc.), USA, and Japan, different AIZES systems have been applied at the agricultural sector (recently also in Macedonia, Serbia, and Moldavia). In those research/development, waste from agricultural activities are upgraded in order to generate renewable energy sources—alternative energy is reused for production on site, or a consortium of businesses in the area. The upgrading of waste to energy carriers can be done through mechanical or thermal processes (drying, pressing, etc.), chemical processes (pyrolysis, torrefication, etc.), or biochemical processes (biogas, alcohol fermentation, etc.). Researchers at Parthenope University of Napoli, Italy, proposed the integrated solutions in agro-based industrial production by combining the elements from agriculture, industry, and energy towards sustainable development goals [49]. Huixiao Wang and colleagues have proposed an eco-agriculture system by linking gases: wastes from chicken, cow, pig, etc. manure are used to produce gas, and this gas is used for those activities requiring energy need in the same livestock farm, and solid sludge from biogas tank is used to make organic fertilizer for that farms [50]. Hai L. T. conducted a research on sustainable agro-industry systems applying to food processing industry in Vietnam. In that research, the material, energy, and monetary flow at a processing factory are analyzed and closed with aims to minimize the need for additional material from outside sources as well as minimize the need for disposing waste into the environment, e.g., towards zero emission within that factory [51].

The barriers for environmental management at the craft villages in Vietnam were indicated in the works of Chi [1] and Hai [47]: poor human awareness (low educational level, insufficient knowhow on serious environmental impacts from the dangerous pollutants); high construction cost for waste treatment facility (for instance, treatment cost for 1 m^3 seafood processing wastewater is approximately 1000 USD); complicated operation procedures for wastewater treatment system (waste treatment technology requires personnel having sufficient knowledge/skill which is not applicable at the rural households); operation costs (not acceptable for every household causing the system to stop or be operated in an irregular/inefficient way); coupling between production and livestock activities, which are very familiar at Mekong Delta, Vietnam, leads to high negative impact to the environment; poor and/or lack of infrastructure is common problem in developing countries; and close relationship between the community and local authority causes obstacles when conducting activities in environmental management at the local rural areas. Among the barriers, the hardest are investment and operation costs of waste treatment facilities [47]; thus, an appropriate system which overcomes those barriers is highly required. For the small-scale livestock farms (30–50 pigs), lack of biogas plants is explained by the lack of household's budget [52], and most of the households in the craft villages do not apply any waste treatment measures [1, 47]. In general, the local authorities fail to apply the environmental regulation at the craft villages [53, 54].

In brief, for resolving environmental pollution problem together with maintaining sustainable livelihood for local inhabitants at the craft villages in rural areas, the ecological techniques coupling to other solutions such as the use of renewable energy/materials/fuels, reuse/recycling, closing energy, and material loops are most appropriate. As indicated above, some "less waste" systems on the basis of these techniques have been developed by Kaufmann [8] and Mol [55]; however, these systems have been applied at larger area scales which are not suitable for the family scale at the sedge mats villages under this study.

Methods

System components

On the basis of characteristics of sedge mats (weaving/dyeing) production, this study use bio-fuel (biogas) instead of polluted fuels, applies technique for converting organic waste into composting fertilizer, and eco-technique for wastewater treatment. The integrated system incorporating these solutions (so-called VICRAIZES: Vietnam Craft villages Agro-based Industrial Zero Emission System) is described in Fig. 5.

System design

The VICRAIZES system is designed based upon the input parameters: number of members at the household; production capacity; pond area, garden area, etc., which are used for the calculation of energy demands for family need and craft production (boiling of dyeing pan); number of pigs and volume of biogas digester required, wastewater quantity discharged, quantity of garbage, load of emission gases, greenhouse gases; treatment capability of the pond; and capacity of wastewater treatment system.

Method for assessing system efficiency: system efficiency on environmental aspect is evaluated by the analysis of calculated data before and after system implementation. The economic aspect is assessed by income for or cost covered by the household.

The predefined assumptions and formulas used for VICRAIZES system calculation:

- For wastewater: detailed survey, taking samples for analysis to determine pollution loads (including wastewater volumes generated). Analysis methods for COD, BOD_5, TSS, Color, total N, and total P are SMEWW 5220 (C):2012, SMEWW 5210 (B):2012, SMEWW 2540 (B):2012, SMEWW 2550 :2012, TCVN 6638:2000, and SMEWW 4500-P (B&D):2012, respectively.
- For emission of gases/greenhouse gases: calculation following the guidance of the IPCC is as follows: $E_{j,f} = M_{\mathrm{f}} \times E_{fj,f}$, in which $E_{j,f}$ is the load of emission gas j of types of fuel used in the combustion/incineration, kg/year; M_f is the amount of fuel consumption, tons/year; $EF_{j,f}$ is the fixed emission gas coefficient j for the type of fuel f, kg/tons fuel.
- For solid waste: using surveys, measurements, and energy/material balances to determine the volume and composition of solid wastes.
- Determining heat for cooking the dyeing pan: $Q = mc(T_1 - T_0)$, in which, Q is the heat necessary(kj), m is the volume of solution to be heated (kg), c is the specific heat kj/kg.degrees, T_1 is the temperature needed to reach (°C), and T_2 is the initial temperature (°C).
- Determining volume of biogas needed for cooking the dyeing pan: $V_{\mathrm{dyeing}} = Q/q$, in which, V is the biogas volume (m^3), Q is the heat necessary (kj), and q is the calorific value of 1 m^3 biogas (kj/m^3).
- Determination volume of essential biogas for living activities at the household (5 person household): $V_{\mathrm{family}} = 1$ (m^3).
- Determining total volume of necessary biogas: $V = V_{\mathrm{dyeing}} + V_{\mathrm{family}}$ (m^3).
- Determining weight of essential pig manure: $m_{\mathrm{manure}} = V/Y$, in which Y is the biogas norm generated from pig manure (40–60 l/kg/day) and from people (60–70 l/kg/day).
- Determining the number of essential pigs: $N_{\mathrm{pig}} = m_{\mathrm{manure}}/p$, in which p is the weight of the cattle feces discharged per day, $p = 1.2–4.0$ (kg/day).
- Determining volume of biogas tank: $V_{\mathrm{biogas}} = (m_{\mathrm{manure}}.3.T)/1.000$, in which T is the manure retention time (days).
- Determining pollution load of wastewater sources: measurement and sample analysis.

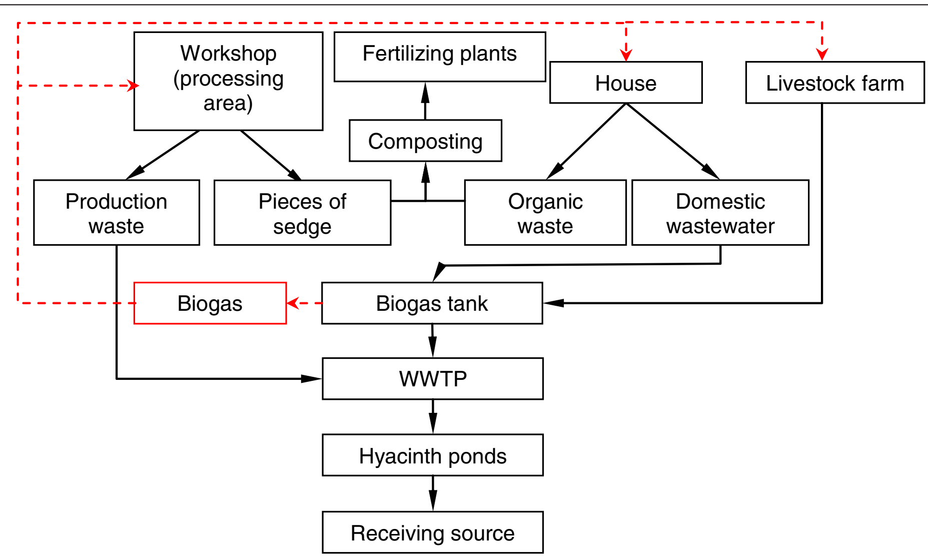

Fig. 5 Main components of the system

– Determining treatment capacities of pond(s) (if any):
 + Actual retention time of the pond = volume of pond (m^3)/capacity of wastewater (m^3/day)
 + Actual treatment capacity of the pond:
 $t_{tt} = \frac{L_a - L_t}{k_t . L_t} \;\; => L_t = \frac{L_a}{t_{tt}.k_t + 1}$
 In which L_a is the BOD_5 of input wastewater (mg/l), L_t is the BOD_5 of output wastewater (mg/l), t_{tt} is the wastewater retention time of the pond (day), k_t is the temperature coefficient, $k_t = k_{20} . C^{(T-20)}$, k_{20} = 0.5–1, for domestic wastewater, k_{20} = 0.3–2.5, for industrial wastewater, C = 1.035–1.074 for natural pond, C = 1.045 for pond having supplement artificial gas, and T is the temperature of pond (°C).
 Determining the capacity of wastewater treatment plant: If the pond itself is capable to treat wastewater ($L_t < L_{standard}$), no need to build treatment plant; If $L_t > L_{standard}$, capacity of wastewater treatment plant designed to treat quantity of pollutants: $L_{wwt} = L_t - L_{standard}$. In which, $L_{standard}$ is the BOD_5 concentration given in Vietnam standard, L_{wwt} is the BOD_5 concentration needed to design wastewater treatment plant (WWTP); If household does not have any pond, capacity of wastewater treatment plant designed must cover to treat whole quantity of pollutants: $L_{wwt} = L_a - L_{standard}$.

Results and discussions

Design calculation for typical household

The research team has conducted a detailed investigation and design calculation for a typical household in the craft village. There are 14 persons working at the Mr. Tam's household (4 in the family and another 10 employees), a processing flow chart describing all technology steps is shown in Fig. 1, and mats weaving capacity is 100 products/day. Consumption of dyes solution is around 300 L per day. The fuel used for cooking the dyeing pans is pieces of sedge: 30 kg for one burning batch. There are 30 pigs at the livestock farm, and there is no biogas plant. There is 1000 m^2 garden for short-term planting and 1500 m^2 empty ground. There is an 80-m^3 pond covered with water hyacinth (a typical aqueous plant in Mekong Delta area). The results from design calculation are as follows: energy demand needed for boiling dyeing pan is 140,400 KJ/day, number of pigs necessary for covering this energy demand is 45 (pigs), necessary volume of biogas digester is 13.46 m^3, total quantity of wastewaters from different sources is 2.5 m^3/day (from domestic: 0.5 m^3/day, from dyeing: 0.2 m^3/day, and from livestock farm: 1.8 m^3/day).

This calculation indicates that the household needs to broaden the livestock activity, to invest the biogas digester system, the composting system using process and domestic solid wastes, to upgrade the existing drainage system and ponds for wastewater treatment, and to invest the system of anaerobic tanks.

Site demonstration

The construction and operation time for VICRAIZES system implementation is within 3 months (Fig. 6). Parameters of system components are presented in Table 2.

Description on VICRAIZES system operation

As described above, the household currently uses pieces of sedge from the sedge mats weaving process for cooking at the dyeing pan which generates environmental pollution. In order to decrease this pollution, the solution is to construct biogas tank with purpose to recover biogas and use as fuel at the dyeing pan (instead of pieces of sedge) and also at other cooking demand of family kitchen. Pieces of sedge are then collected together with other biodegradable domestic waste at the family and go to composting tank for production of fertilizer for further use at the garden. To support the composting process, wastewater after biogas tank (containing microbial components that could decompose organic matter) is pumped and watered over the composting materials along with fungi Trichoderma. Function of fungi Trichoderma was described by Toghueo, Ha and Hoa [56, 57]. Non-degradable household solid waste is collected and sold out (collection of valuable components in the garbage and sell to the recycling market is an existing service at local area). Wastewater including processing, domestic wastewater, and wastewater after biogas tank are then collected and treated by using a combination of the existing hyacinth ponds and newly-built WWTP (wastewater treatment plan).

Results obtained

This VICRAIZES system is developed on the basis of the solutions from previous studies such as the system implemented by Kaufmann [8]: use of livestock waste for biogas recovery, the methane gas recovered is used for family cooking, and residue after biogas tank is used as fertilizer, or the systems using constructed wetland coupling with available local plants (water hyacinth) for wastewater treatment. However, the previous systems have concentrated (focused) only on one type of waste (livestock waste or wastewater), and quality of effluent wastewater does not meet environmental standard. In this paper, the system does not only help the households in satisfying the existing environmental regulations (effluent wastewater meets standard QCVN 40:2011/BTNMT), but also the investment and operation costs of the system are both lower which fit with practical requirement from the households in craft villages; moreover, it helps to increase the income

Fig. 6 The system components is being under construction

for the households and to maintain the sustainability of the rural craft production.

Air emission

Quantity of methane gas recovered from biogas digester is 4.6 m^3/day. This gas quantity could replace completely the fuels for dyeing process and domestic need. The data given in Table 3 show a significant reduction in all gas emissions if compared with data given in Table 1.

In brief, the use of biogas recovered from biogas system for boiling the dyeing pan instead of burning the pieces of sedge helped to reduce gas emission almost totally. For the large livestock farms, there is a surplus of biogas quantity which predominates the cooking and lighting needs, and this leads to CH_4 emission into the environment [52] and causes a waste in renewable energy and an increase in greenhouse gases emission. In this VICRAIZES demonstration system, besides the use of biogas for cooking demand at the family, the surplus biogas was used for heating the pan with dyeing solution, and by this way, greenhouse gases emission from surplus biogas and waste emission from burning pieces of sedge mats (for heating the dyeing pan) were both reduced or eliminated.

Wastewater

All wastewater sources are entirely collected and led into wastewater treatment system, the analytical results of wastewater quality after treatment system as follows: pH = 7.31; BOD_5 = 19 mg/L; COD = 49 mg/L; TSS = 31 mg/L; color = 126 Pt-Co, total *N* = 29.37 mg/L, total *P* = 0.98; *coliforms* = 60 MPN/100 mL, and all meet Vietnamese standard QCVN 40:2011/BTNMT for industrial wastewaters (pH = 5.5–9, BOD_5 = 50 mg/L, COD = 150 mg/L, TSS = 100 mg/L, color = 150 Pt-Co, total *N* = 40 mg/L, total *P* = 6 mg/L). As indicated in the works of Kaufmann [8] and Sulca [4], both suggested that the wastewaters and solid wastes from livestock farms are directly applied for plant cultivation, while these waste flows (after bio-digester) are commonly discharged into environment in Vietnam Thu [52]), and these flows do not certainly meet the local standards as required in QCVN 40:2011/ BTNMT for both wastewaters from livestock and sedge mats production. Thus, at the low income condition of the family in the craft villages, the investment of standard waste treatment system for meeting with required regulations are practically not applicable; therefore, the VICRAIZES demonstration system under this study is proved to be a good choice for wastewater treatment at the craft villages.

Solid waste

Almost 100 % solid waste is collected for reuse, and recycled, biodegradable domestic solid waste together with production solid waste (pieces of sedge) is composted to produce organic fertilizer and to be used for household garden; non-biodegradable domestic solid waste is collected for recycling purposes in the local market in the surrounding area. Pieces of sedge are not used anymore

Table 2 Parameters of system components

Items	Description
Biogas recovery system	Number of pigs: 45, volume of biogas tank (material: composite): 14 m^3, the biogas recovered is used for cooking at dyeing pan and other living activities (at kitchen).
Wastewater treatment plant	Total volume of wastewater treatment plant (compacted as a block): 10 m^3, having 4 compartments (anaerobic combined with filter), wastewater treatment loading capacity (accordance with BOD_5): 1.087 kg/day. Volume of water hyacinth pond: 80 m^3 which corresponds to wastewater treatment loading capacity (accordance with BOD_5): 7.35 kg/day.
Composting system/tank	Composting area is 4 m^2, materials: 100 kg pieces of sedge + 1 kg *Trichoderma* (bio-product), incubated for 30 days, the moisture of 50-55 % is kept by watering with wastewater flow after biogas tank, and the temperature during composting process is kept by covering the tank surface.

Table 3 Volumes of gases/greenhouse gases (GHG) emitted after system demonstration at the typical household

Type of fuel	Load of emission gas (tons/year)[a]					Load of GHG (tons/year)[b]			Ton of CO_2eq/year
	Dust	SO_2	VOC	NO_x	CO	CO_2	CH_4	N_2O	
Baseline (use of production waste)	151.48	3.29	127.75	41.61	1697.25	21.48	0.18	–	25.16
Biogases	18×10^{-3}	0.3×10^{-3}	–	113×10^{-3}	0.3×10^{-3}	1.677	29×10^{-6}	29×10^{-7}	1.677
Reduction (%)	99.9	99.9	–	99.7	99.9	92.1	99.9	–	93.3

[a], [b]Calculated by the formula: activity data × mission factor, in which, [a]Emission factor is taken from WHO, 1993; [b]Emission factor is taken from IPCC, 2006

for cooking at dyeing pan but are collected together with organic domestic solid waste for composting. An amount of 100 kg of those solid materials are composted for 30 days (supplemented by 1 kg *Trichoderma*) produced about 15 kg organic fertilizers and used for the household garden. In brief, the VICRAIZES system helped to manage completely all the solid wastes generated in the family, while the system suggested by Kaufmann [8] has applied at the larger area scope and led to less waste emission from livestock farms only.

Socio-economic benefits

The VICRAIZES system investment cost (breeding facility, breeding pigs, food, electricity, water, veterinary medicine, manpower, wastewater treatment plant, biogas digester, etc.) is approximately 569,000,000 VNĐ/year (25,800 USD), and benefits gained (by selling pigs, biogases) are about 684,125,000 VNĐ/year (31,090 USD), i.e., the additional income for household is 115,125,000 VNĐ/year (5290 USD). The detailed numbers are given in Table 4.

The system could be considered as a sustainable livelihood system for the households in the sedge mats craft villages due to the increase in incomes from livestock activity, use of organic fertilizer for decreasing cultivation cost, use of biogas instead of other fuels, etc. Meanwhile, the system also helps to minimize the pollution (wastewater, air emission, solid waste) and satisfies the requirement from environmental regulation. The system consists of the traditional components such as biogas tank, anaerobic tank, and composting tank which do not require high qualified or skilled technical personal for operation and do not use equipment/instruments, chemicals, etc. There is almost no operation cost (except the costs of manpower, breeding food, livestock farm, etc.) as described in Table 4. The households can easily work with the system; therefore, the ability in multiply/transfer to other similar households is a real fact.

Conclusions

The research has assessed environmental status at the sedge mat craft villages in Mekong Delta, including three main pollution sources (emission gas, wastewater, solid waste). On that basis, an ecosystem is demonstrated with the purpose to decrease pollution for specific object following the idea of an Agro-based Industrial Zero Emission Systems (AIZES). Main material and energy flows are closed by applying measures: biogas recovered from

Table 4 Efficiency on economic aspect of the VICRAIZES system at typical household

No.	Content	Benefits (VND/year)[a]	Costs (VND/year)[a]
1	Suppy biogas instead of pieces of sedge mats (for burning dyeing pan)	9,125,000	0
2	Income gained from selling pigs	675,000,000	0
3	Food for feeding pigs	0	270,000,000
4	Manpower for livestock farm	0	36,000,000
5	Electricity, water use	0	6,000,000
6	Veterinary medicine	0	24,000,000
7	Breeding pigs	0	162,000,000
8	Breeding facility	0	33,750,000
9	Amortization of breeding facility	0	1,100,000
10	Biogas digester system	0	14,000,000
11	Wastewater treatment system	0	21,000,000
12	Amortization of Wastewater treatment system	0	1,150,000
	Income = benefits – costs	115,125,000	

[a]1 USD = 21,500 VN Dong

biogas tank for cooking the dyeing sedge, replaced traditional burning fuels, and contributed to decrease polluted gas emission, and pieces of sedge together with biodegradable domestic solid waste are used for composting to produceorganic fertilizer and used to fertilize the household garden, taking advantage of existing biological ponds and flora (*water hyacinth*) available at local site for the reduction of investment and operation cost of waste water treatment plants etc. The results of system implementation of the so-called VICRAIZES (Vietnam Craft villages Agro-based Industrial Zero Emission Systems) show benefits/advantages on environmental, economic, and technical aspects giving real chances for more comprehensive application at similar craft villages in Vietnam and possibly in another developing countries.

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Authors' contributions
THL initiated the research idea and developed the VICRAIZES system. He also designed and organized the whole research of this study. VTT has a lead role in the literature review and the setup of VICRAIZES system. QVL was the site engineer who brought the VICRAIZES system into application in a number of sedge mats dyeing and weaving household craft villages in the Mekong Delta areas. TPTN is responsible for the communication with the other partner during the site survey and data acquisition. HS and GB contributed in the research idea development and zero emission application for the system. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

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